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Scroll Compressor Cupping Analysis

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ABSTRACT

A methodology is outlined for obtaining an estimate of optimum cupping, or wrap height profile, in a scroll compressor. Finite element analyses are performed on models of the scroll parts under both mechanical and thermal loading, to yield their deflected shapes. The mechanical loading is obtained from a dynamic simulation while the thermal loading is derived from temperature measurements on a running scroll compressor. Operating condition dependencies are addressed by repeating the analyses over a range of conditions. An analysis of these various results leads to an initial cupping profile for the scroll parts.

INTRODUCTION

Scroll compressors depend on tight clearance between their mating parts, to minimize leaks between pockets of refrigerant gas at various stages of compression. Both radial and axial clearance is held minimum through tight manufacturing tolerances. The axial clearance between the tips of one scroll part and the baseplate of its mating pair though, can be adversely affected by distortion that occurs in the parts under conditions of operation. Parts machined to mate well while unloaded, will not do so when subjected to the unique thermal gradient and pressure differential inherent in a scroll compressor.

The wraps and internal side of the baseplate of a typical operating scroll are exposed to gas pockets of increasing temperature and pressure from outside to inside (decreasing unwrap angle). In general, thermal expansion causes the wraps to increase in height axially at the interior of the scroll. Meanwhile, the baseplate to which the wraps are attached deforms axially in response to the difference between the pressure in the scroll pockets and that acting on its opposite side. Typically, the result of these changes under operating conditions is that only the innermost wrap areas make axial contact with the mating part. The detrimental effects of this are twofold. Portions of the wrap tip have clearance relative to the mating baseplate, creating a refrigerant leak path. Also, the orbiting scroll, in attempting to ride on the inner wraps only, is susceptible to undesirable wobbling. The goal of cupping analysis then is to define wrap height curves for the unloaded parts, that will optimize the axial mating performance of a scroll pair during operation.

Solid models of the scroll parts are utilized in this analysis. Although this analysis only results in suggestions for axial modification of the scroll parts, some aspects of the modeling are 3D in nature. The analysis will therefore, account for any axial effects resulting from radial constraints or forces. Some consideration was given to modeling two different axial contact designs. One has axial contact only between the tips of one scroll and its mating parts baseplate. It is referred to as a tip rider. The other is designed such that an alternate axial surface, typically a flange on the outer periphery of the fixed scroll part, contacts an accommodating surface on the orbiting scroll part, and is referred to as a face rider. In some cases, tip riding and face riding is combined.

FINITE ELEMENT ANALYSIS OF SCROLL PARTS

A separate finite element analysis (FEA) is performed on both the fixed and orbiting scroll parts to predict their deformed shape under load. The deflection of the scroll parts is derived including the effects

of both mechanical and thermal loading. Generally the analysis is carried out in a manner to allow discernment of their individual contributions to deflection. Additionally, the analysis is carried out for 3 different operating conditions: ARI; CHEER; and Max Load. In order to perform the FEA, solid models of the two scroll parts must be created and meshed. Typically, auto-meshing works adequately except in the region of the wrap tips. The elements in this region are subject to revision by hand.

The mechanical portion of the analysis features pressure load application closely resembling that experienced during operation. The backs (opposite the wraps) of the scroll parts are loaded with pressures appropriate for the condition being modeled. Typically the back of the fixed scroll experiences discharge pressure while the orbiting scroll is divided between an intermediate pressure circle at its center and suction pressure around its outer area. Loads simulating the internal wrap pocket pressure come from one of two methods. The more direct approach is applying pressure loads to the elements on the wrap side surfaces of the models in accordance with a map of equal pressure zones, calculated by an in-house simulation program. Figure 1 displays an example map of these pressure zones created by the interaction of the involute walls of the mating scroll parts, for a particular point in the compression cycle.

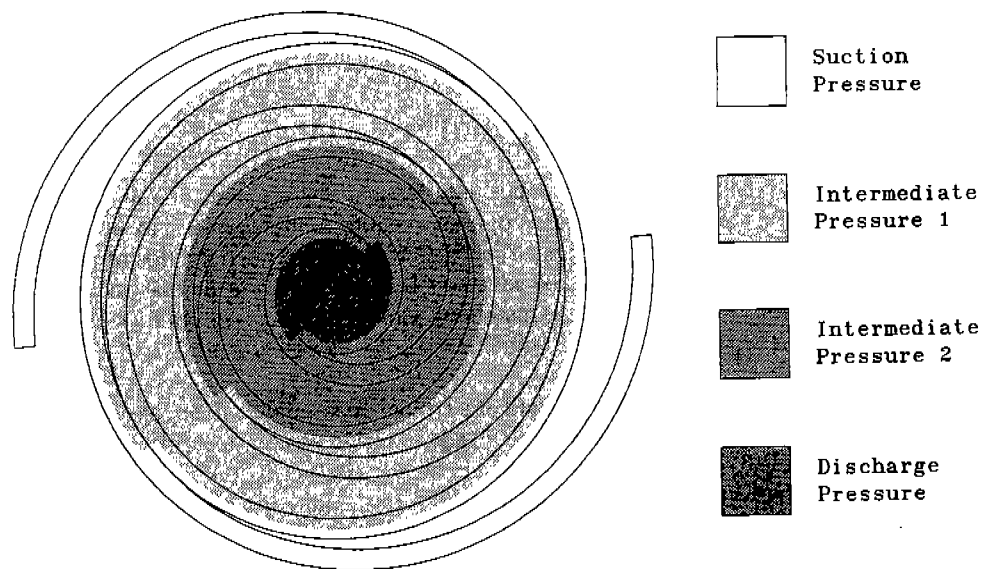


Figure 1. Zones of Equal Pressure on Axial Surfaces of Scroll Model

Obviously, this approach requires the choosing of a particular point in the orbit cycle that is either representative of the entire orbit cycle or thought to have some critical significance.

A second approach to modeling internal pocket pressures can also be applied. This method assigns a pressure, between suction and discharge, to the surface elements in accordance with a linear function on unwrap angle. This approach requires a utility for generating loads according to a function on location. A special purpose program outside of the FEA software that could discern location and apply loads to an existing model was developed. The results obtained through these two different models of internal wrap pressure yield similar results for this mechanical modeling portion of the cupping analysis.

Thermal analysis involves a two step process. Temperatures are measured and recorded at several key locations of the operating scroll parts. Thermocouples are located both in the wraps as well as on the back of the baseplate opposite the wraps. The first modeling analysis step then is solving a heat transfer model for the scroll part iteratively, until the analytically predicted temperatures in the model match those measured on the actual operating part. The resulting nodal temperature profile is then imposed on the model in step two. Thermal expansion calculated in this analysis step causes a deflection pattern in the scroll models that makes up the thermal modeling portion of the cupping analysis.

SYNTHESIS OF THE FINITE ELEMENT ANALYSIS RESULTS

The net distance between mating axial surfaces of the two parts is calculated by combining the deflection results from our FEA work. Because a goal of cupping is to eliminate non-uniform contact between the mating parts, this step is carried out allowing the deflections on each part to occur without regard for limitations related to interference with its mate. The relationship of the mating axial surfaces of the parts to each other is derived by combining the FEA deflection results in such a manner as to calculate the net axial distance between locations on the two parts that would actually be in proximity during operation. A capability of the FEA post processor utilized is that it easily relates deflection results to location expressed as arc length along the edges of the wraps. If we subtract a half unwrap (180°) offset, arc length equivalent, from that of the baseplate results on one part, we establish a rough correspondence between locations on the two parts that will mate axially during orbiting operation. With this offset applied, axial deflections from the two separate parts associated with equivalent arc lengths can be compared directly to each other.

For discussion purposes, it is helpful to separate the various components contributing to the axial gap or interference calculated. A convention used here is to define movement in the direction from the baseplate toward the wraps, on either part as positive (interference). Movement in the opposite direction is then defined as negative (gap). In analyzing the orbiting scroll cupping, or the relationship between the orbiting scroll wraps and the fixed scroll baseplate, two components come from our mechanical modeling. Both the orbiting and fixed scroll baseplates are subject to deformation, and will effect the axial interference being calculated. Additionally an effect from thermal growth of the orbiting scroll wraps must be included. By summing these three components at equivalent arc length locations, a curve of the net interference at any location along the length of the orbiting scroll wrap can be generated. Likewise, for the fixed scroll cupping, the mechanical distortion of the two baseplates is combined with the thermal growth of the fixed scroll wraps.

If the scrolls are of the face-riding variety, an additional consideration must be made. It is likely that the additional flange around the periphery of the fixed scroll part will induce axial movement of the fixed baseplate due to thermal effects. As the elements on the interior of the flange seek to thermally expand they are resisted by those elements located radially outward. The result is a tendency toward axial movement or warping of the baseplate. This additional deflection will inherently be included in the thermal deflection of the fixed scroll tips. This thermal deflection of the fixed scroll baseplate however, must also explicitly be added in the calculation of interference between the orbiting scroll tips and fixed scroll baseplate.

OPTIMUM CUPPING

Plots of the total interference between the tips, and their mating baseplate, of each part can be produced relative to arc length along the wraps. An optimally cupped part would be one whose total interference plot was zero everywhere along its arc length. A plot of total interference shows where there is excess material along the wrap tip when under load. Figure 2 shows an example interference plot. Total interference values are generally less than .001 inches (.0254 mm) in magnitude.

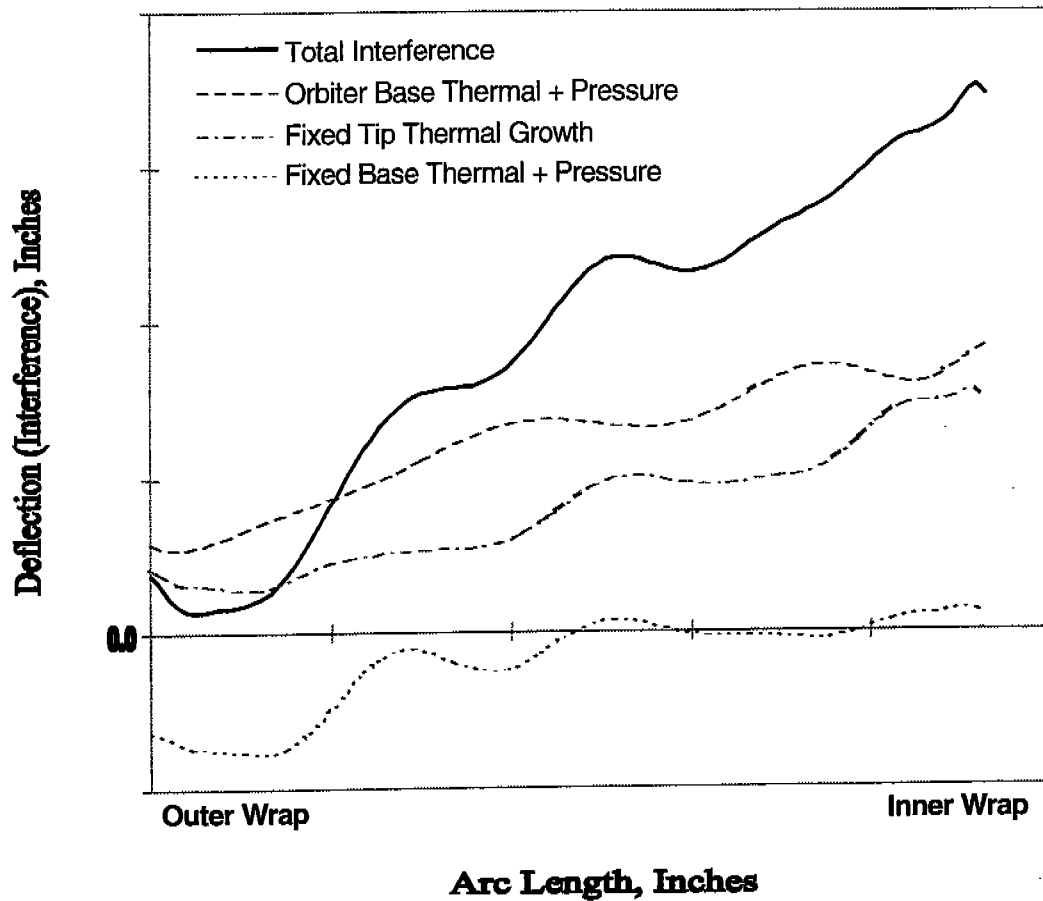


Figure 2. Example Plot of Total Interference and its Components

A cupping profile plot, showing the tip profile under unloaded conditions that will deform when loaded to optimally mate with the opposing baseplate is opposite (negative) to the interference curve. Figure 3 shows a cupping profile plot resulting from negating the total interference curve of Figure 2. In this form, the cupping profile values along the curve represent height relative to nominal height.

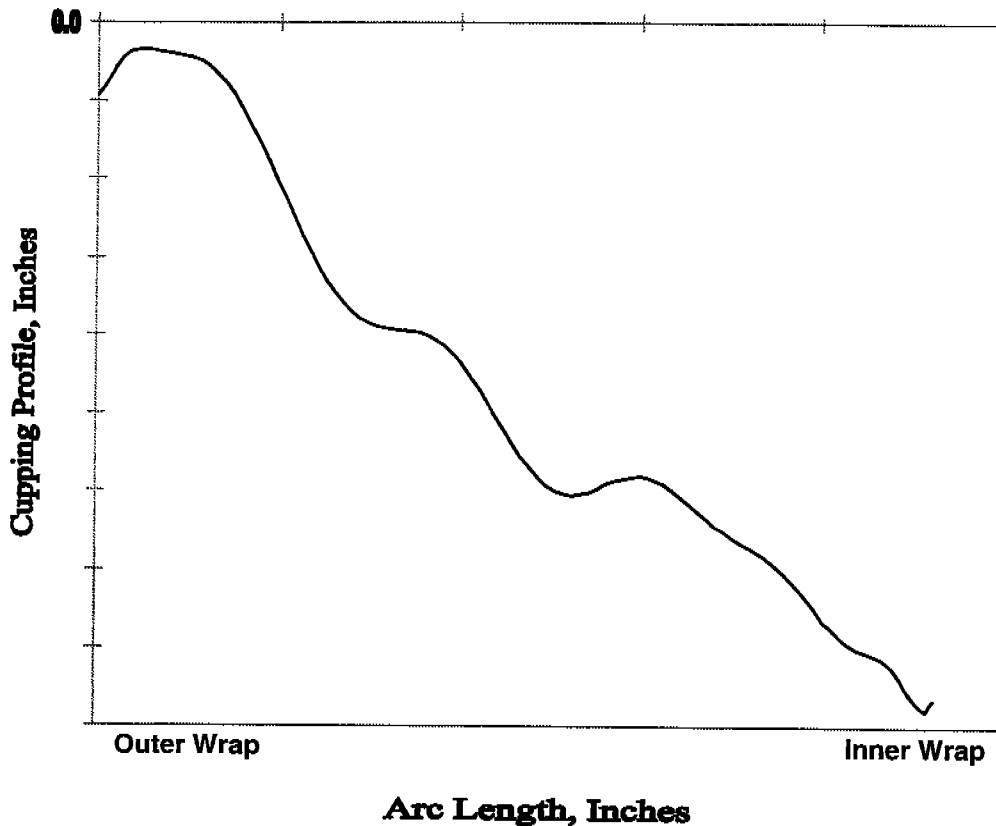


Figure 3. Example Plot of Resulting Optimum Cupping Profile

Because the scroll compressor will likely be exposed to a variety of operating conditions, we chose to include in our analysis a range of three conditions. Consideration must then be given to these three different cupping plots, each optimum only for its particular operating condition. The curves are typically non-linear. Bearing in mind that we have generally analyzed one point in the orbit cycle and that fluctuations in the desired cupping would occur at other cycle points, we attempt to fit a line to the curves, or several lines to sections of the cupping curves. Consideration also must be given to the start-up event, when the thermal expansion deflections would be lessened.

VERIFICATION

To date, modest correlation has been observed between results obtained following this analysis and measurements of mature wrap tips, presumably worn in to some optimum cupping profile. Also, performance increase has been observed related to a cupping profile change suggested by this analysis method.